Assessment of simulated water balance from Noah, Noah-MP, CLM, and VIC over CONUS using the NLDAS test bed

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  - Terrestrial water storage
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RESEARCH ARTICLE

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Key Points:

- Noah-MP provides the best simulations of soil moisture and TWS
- CLM4 shows the best performance in simulating ET
- VIC ranks the highest in performing the streamflow simulations

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Abstract This study assesses the hydrologic performance of four land surface models (LSMs) for

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Introduction

- Importance of land surface models
  - Lower boundary condition in weather/climate models
  - Land-atmosphere interactions and feedbacks
  - Provides fluxes (e.g. ET, sensible heat, runoff) and state variables (soil moisture/temperature, snow)
  - Implement the human influences on the climate system (land cover change, irrigation, dams, fossil fuel burning, etc.)

NLDAS Models and Development

- NLDAS-2 LSM intercomparison (Xia et al., 2012).
  - Noah, Mosaic, SAC, & VIC
- Noah-MP as the next-generation LSM in NCEP; CLM as one of the most sophisticated LSMs in earth system modeling.
- Compared to Noah LSM, CLM4 and Noah-MP have the following advancement.
  - Multi-layer snow model
  - Groundwater model
  - Dynamic leaf model

Objective

- Evaluate these improvements on the same test bed that current NLDAS-2 LSMs were evaluated.

Models		Variables
Noah LSM ■		■ Terrestrial water storage
Noah-MP ■		■ Evapotranspiration
CLM4 ■		■ Soil moisture
VIC ■		■ Runoff

NLDAS Testbed

Model Structures

Model	Vegetation	Soil	Snow
Noah	Dominant vegetation type in one grid cell with prescribed LAI	4 layer moisture and temperature	Single layer
VIC	Tiling in one grid cell with prescribed LAI	3 layer moisture and temperature	Two layers
Noah-MP	Dominant vegetation type in one grid cell with dynamic LAI	4 layer moisture and temperature	Up to 3 layers
CLM4	Up to 10 vegetation types in one grid cell with prescribed LAI	10 layer moisture and 15 layer temperature	Up to 5 layers

What is Noah-MP?

Augmented Noah LSM with Multi-Parameterization options (Noah-MP):

- **Key references**: (Niu et al., JGR, 2011; Yang et al., JGR, 2011)
- **Recoded** based on the standard Noah LSM
- Well documented and highly **modular**
- **Improved biophysical realism (land memory processes)**: separate vegetation canopy and ground temperatures; a multi-layer snowpack; an unconfined aquifer model for groundwater dynamics; **an interactive vegetation canopy layer**

Noah-MP

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, D12109, doi:10.1029/2010JD015139, 2011

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Noah-MP: Noah with Multi-Physics Options

1. **Leaf area index (prescribed; predicted) 2**
2. **Turbulent transfer (Noah; NCAR LSM) 2**
3. **Soil moisture stress factor for transp. (Noah; BATS; CLM) 3**
4. **Canopy stomatal resistance (Jarvis; Ball-Berry) 2**
5. **Snow surface albedo (BATS; CLASS) 2**
6. **Frozen soil permeability (Noah; Niu and Yang, 2006) 2**
7. **Supercooled liquid water (Noah; Niu and Yang, 2006) 2**
8. **Radiation transfer: 3**
   Modified two-stream: Gap = F (3D structure; solar zenith angle; ...) ≤ 1-GVF
   Two-stream applied to the entire grid cell: Gap = 0
   Two-stream applied to fractional vegetated area: Gap = 1-GVF
9. **Partitioning of precipitation to snow and rainfall (CLM; Noah) 2**
10. **Runoff and groundwater: 4**
    TOPMODEL with groundwater
    TOPMODEL with an equilibrium water table (Chen&Kumar,2001)
    Original Noah scheme
    BATS surface runoff and free drainage

2x2x3x2x2x2x2x3x2x4 = 4608 combinations

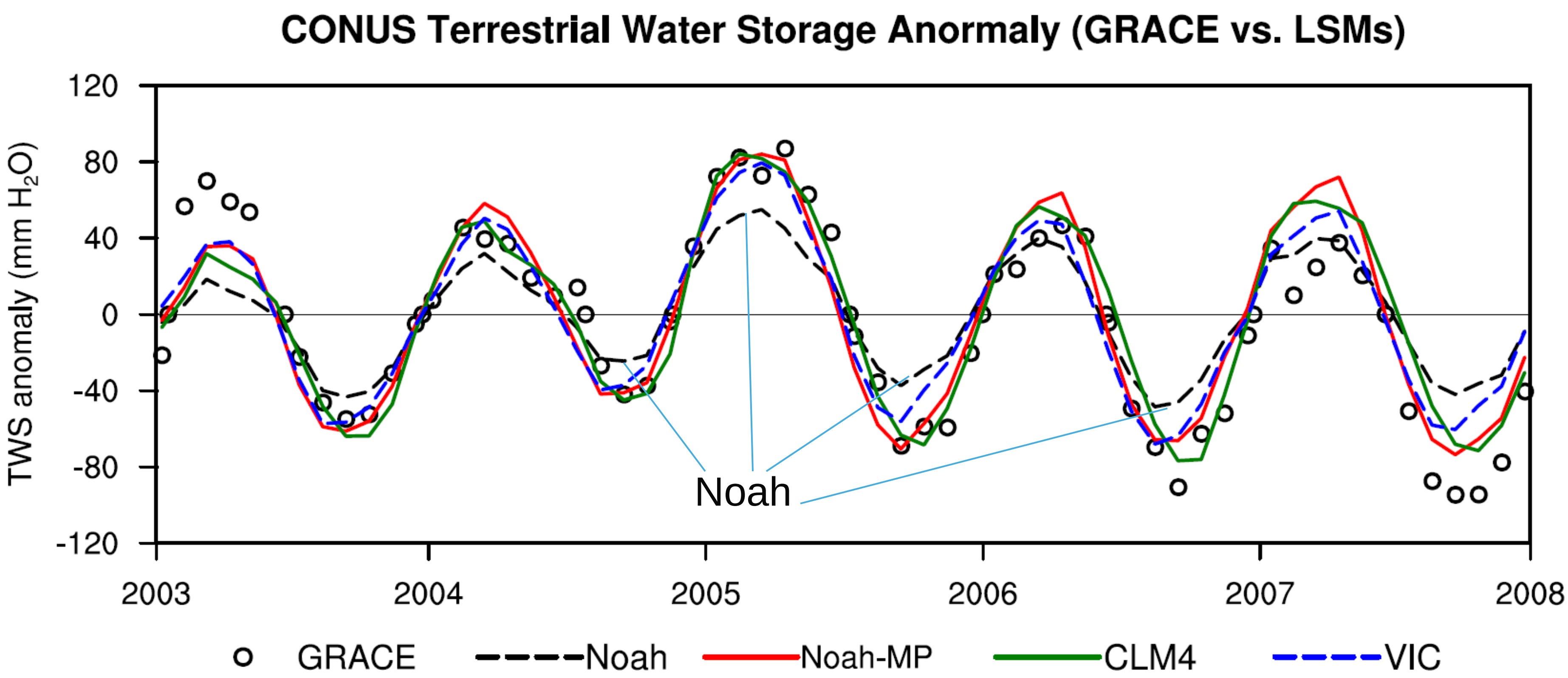
- With these options, we can conduct ensemble modeling using one model.

(Niu et al., 2011; Yang et al., 2011)

Model Setup and Data

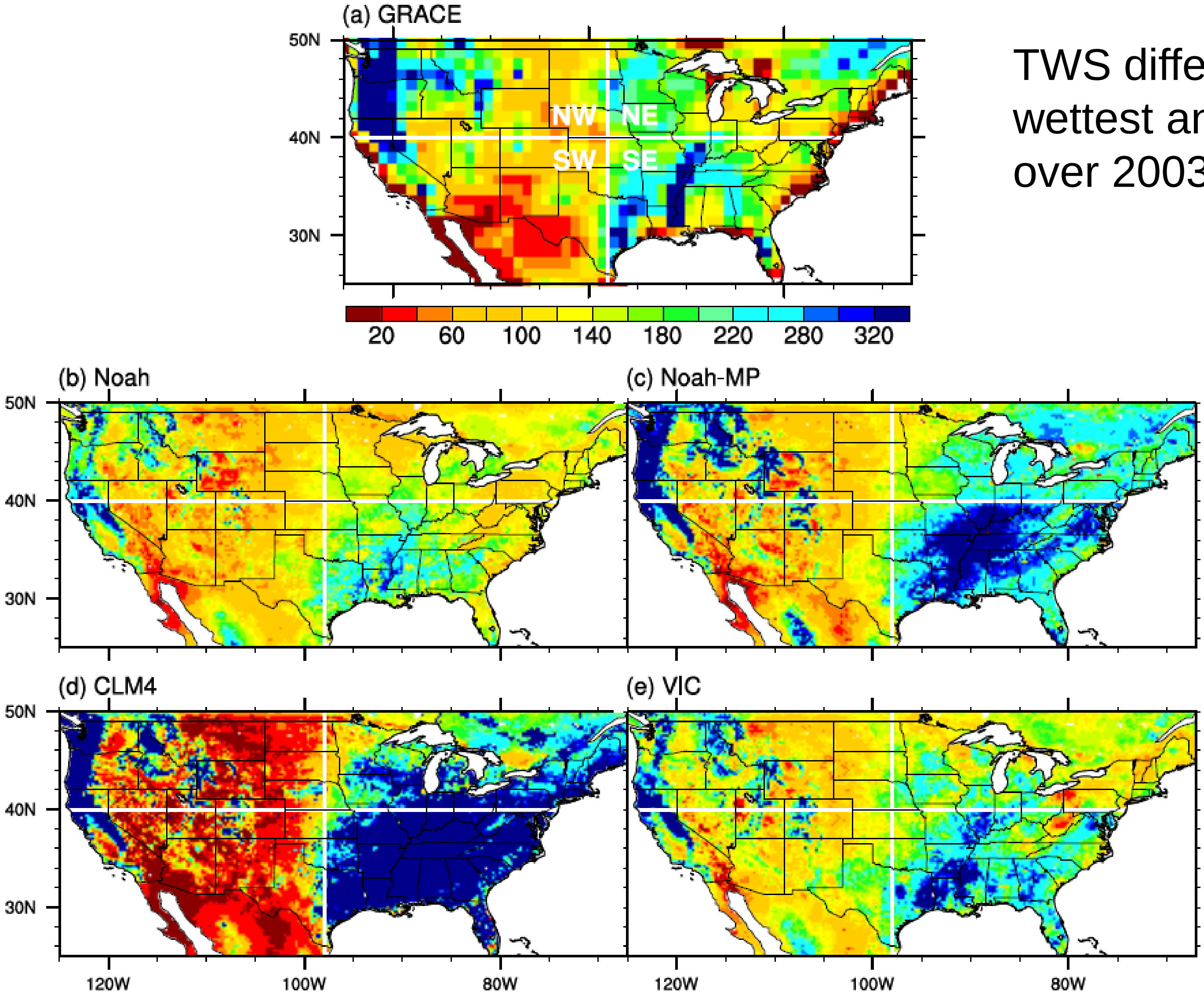
- Model Setup
  - Temporal: hourly from 10/1979 to 9/2007
  - Spatial: 1/8th degree for the CONUS
  - Forcing: NLDAS-2
- Observational data
  - USGS streamflow for 961 small basins
  - MODIS and gridded FLUXNET ET
  - GRACE TWS anomalies
  - SCAN soil moisture

Terrestrial Water Storage—Temporal Pattern



Noah LSM underestimates GRACE TWS amplitude, while all other models capture the TWS fluctuation.

Terrestrial Water Storage—Spatial Pattern



TWS difference between the wettest and driest months over 2003-2008 period.

Terrestrial Water Storage—Statistics

Statistical summary of model performance in simulating terrestrial water storage anomaly

	R^2						RMSE					
Model	NW	NE	SW	SE	Avg.	CONUS	NW	NE	SW	SE	Avg.	CONUS
Noah	0.914	0.739	0.534	0.917	0.776	0.894	30.89	30.41	25.89	34.51	30.42	22.55
Noah-MP	0.962	0.696	0.790	0.932	0.845	0.907	24.47	38.05	19.65	21.97	26.03	15.17
CLM4	0.956	0.683	0.671	0.912	0.805	0.913	26.29	38.81	23.33	57.10	36.38	14.50
VIC	0.933	0.694	0.670	0.906	0.801	0.906	26.10	31.31	22.35	25.16	26.23	15.50
Mean	0.941	0.703	0.666	0.917	0.807	0.905	26.94	34.64	22.81	34.68	29.77	16.93

All R^2 values pass 99% confidence level.

Noah-MP shows the highest skills.

Terrestrial Water Storage—Contributions

$$TWSA_i = SMCA_i + SWEA_i + WTDA_i$$

Among soil moisture, snow, and groundwater, which makes the largest contribution to the TWS anomalies?

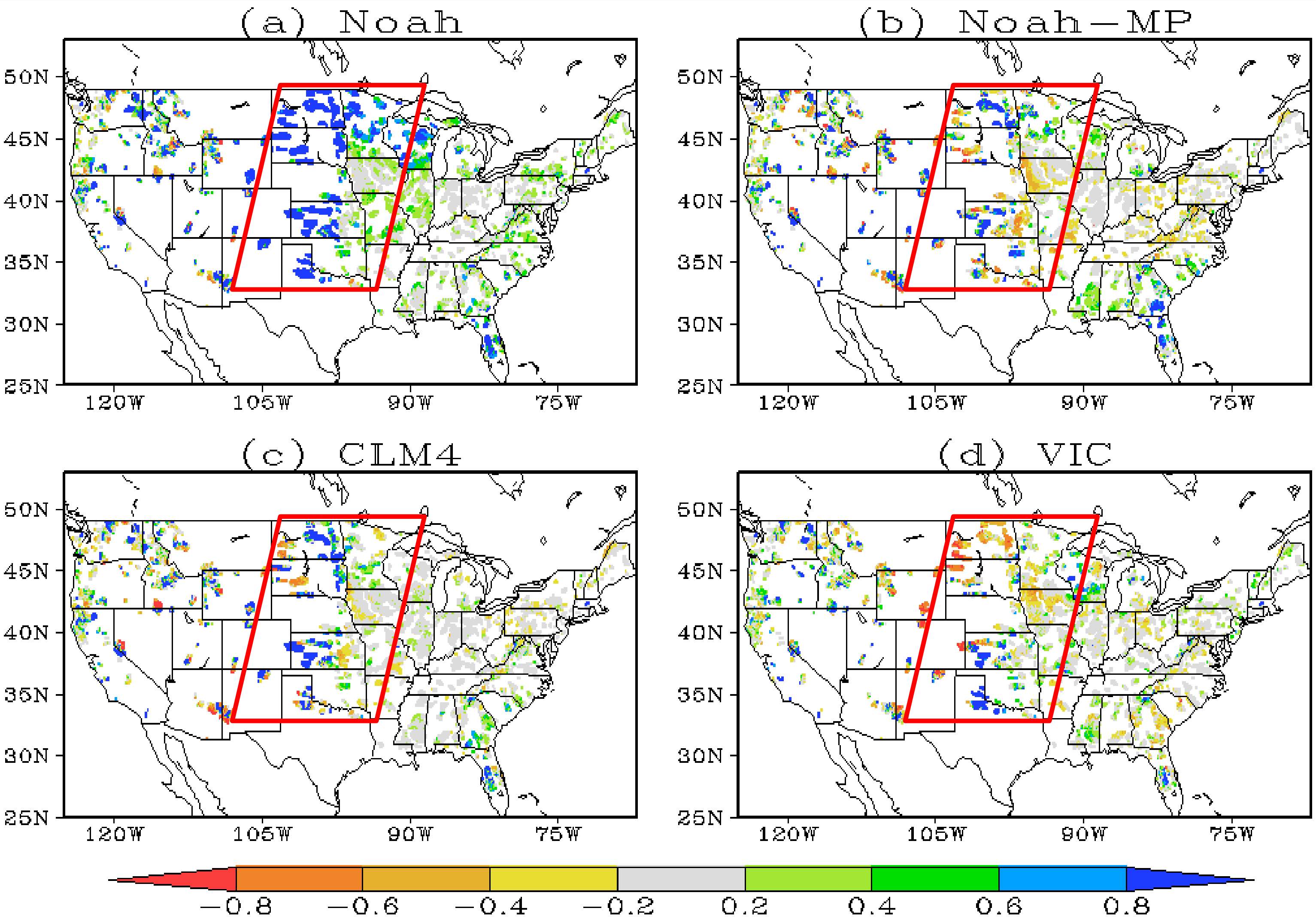
Terrestrial Water Storage—Contributions

	NW			NE			SW			SE			CONUS		
	SMC	SWE	GW	SMC	SWE	GW	SMC	SWE	GW	SMC	SWE	GW	SMC	SWE	GW
R^2															
Noah-MP	44.0	29.6	26.4	48.4	21.2	30.4	33.4	43.8	22.8	50.7	4.2	45.2	42.1	24.4	33.5
CLM4	41.3	20.0	38.7	42.3	16.3	41.4	36.2	37.1	26.7	50.8	0.2	49.0	39.8	18.7	41.5
RMSE															
Noah-MP	25.2	34.2	40.7	28.7	36.5	34.8	29.0	35.4	35.6	19.9	47.2	33.0	23.1	38.0	38.9
CLM4	36.3	36.6	27.0	34.8	35.5	29.8	33.3	35.9	30.8	33.0	40.7	26.4	39.7	42.0	18.3

Each contributes about one third to the TWS anomaly

Depends on model and region

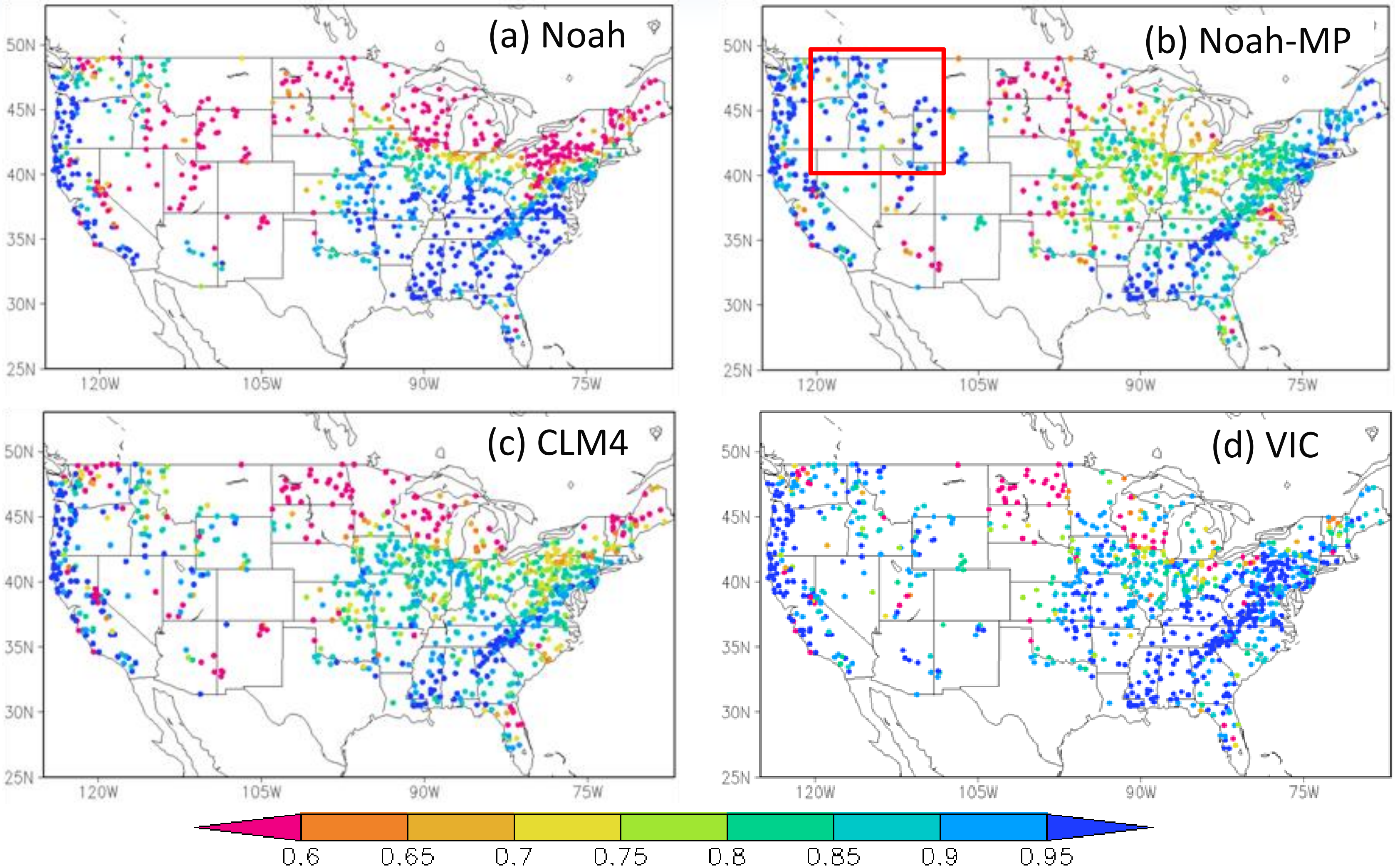
Streamflow Relative Bias (LSMs – Obs)



$$\frac{Mod - Obs}{Obs}$$

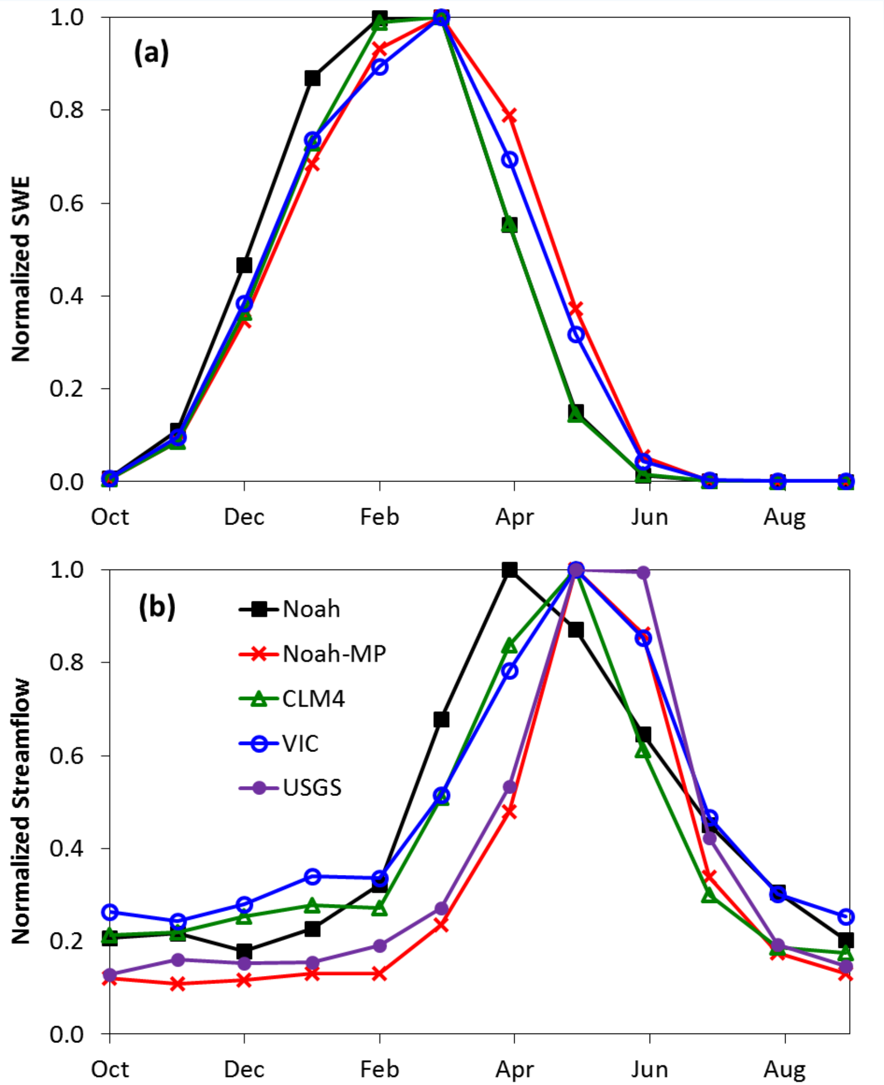
Noah LSM overestimates streamflow; while Noah-MP and CLM4 are comparable with VIC and observation.

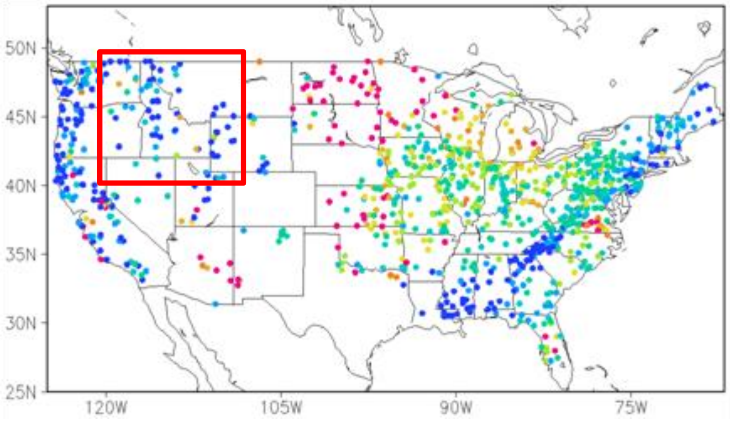
Streamflow Correlations



Noah-MP shows high correlations over the northwest snow region.

Snow Water Equivalent and Runoff



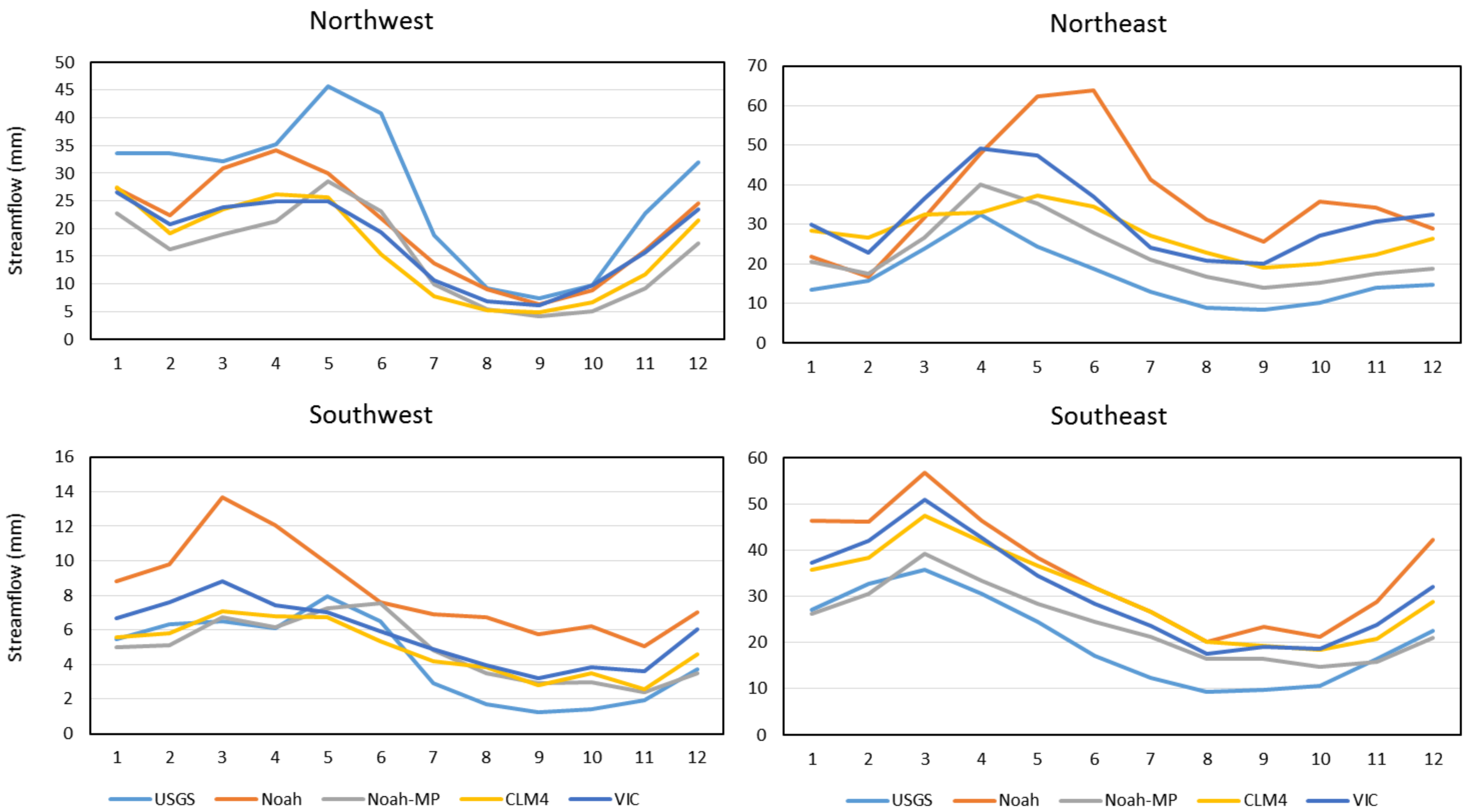


There is about one month timing difference between Noah LSM, Noah-MP.

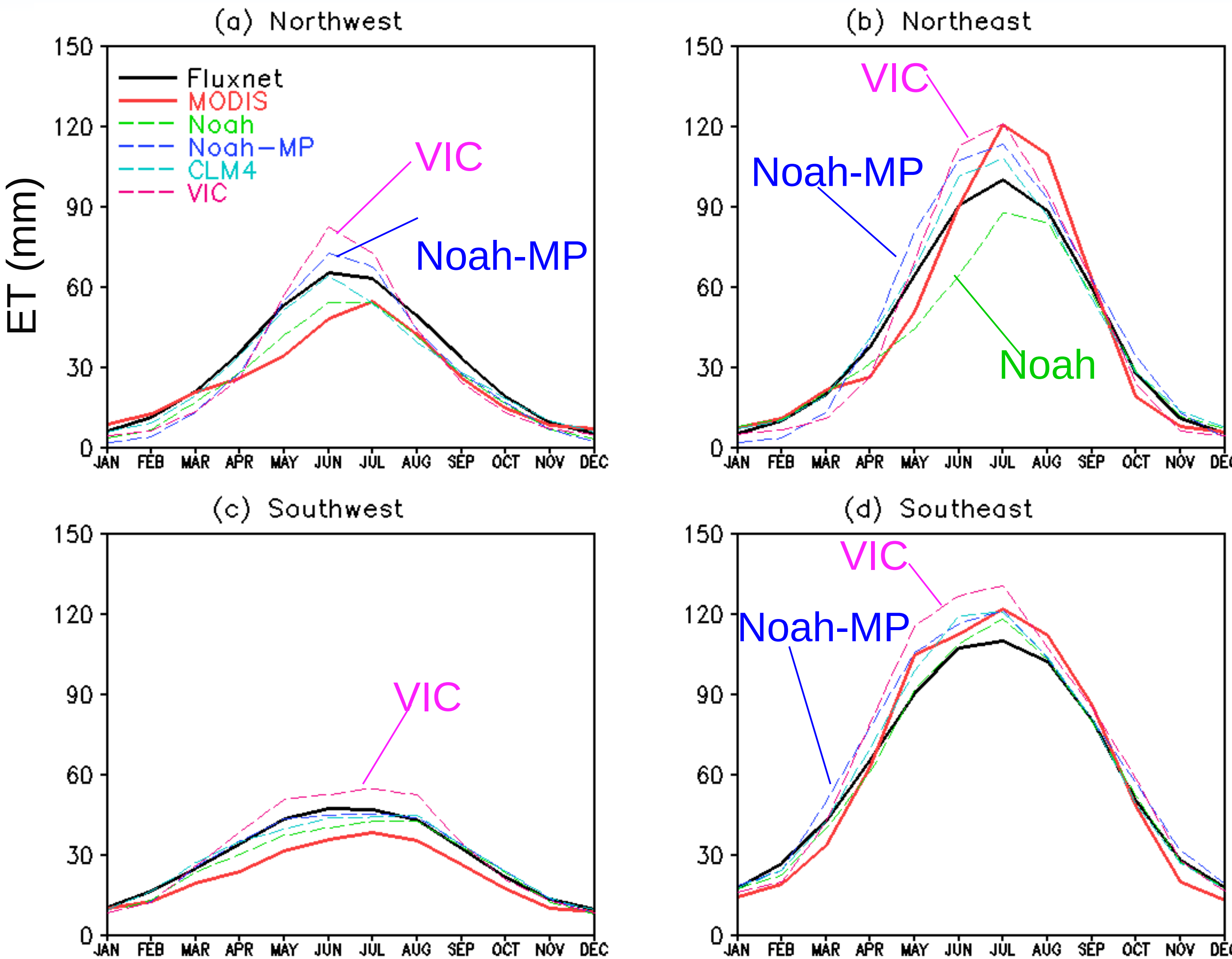
Both CLM and Noah-MP include multi-layer snow structure and groundwater dynamics.

Does this show any value in simulating the streamflow?

Monthly Climatological Streamflow



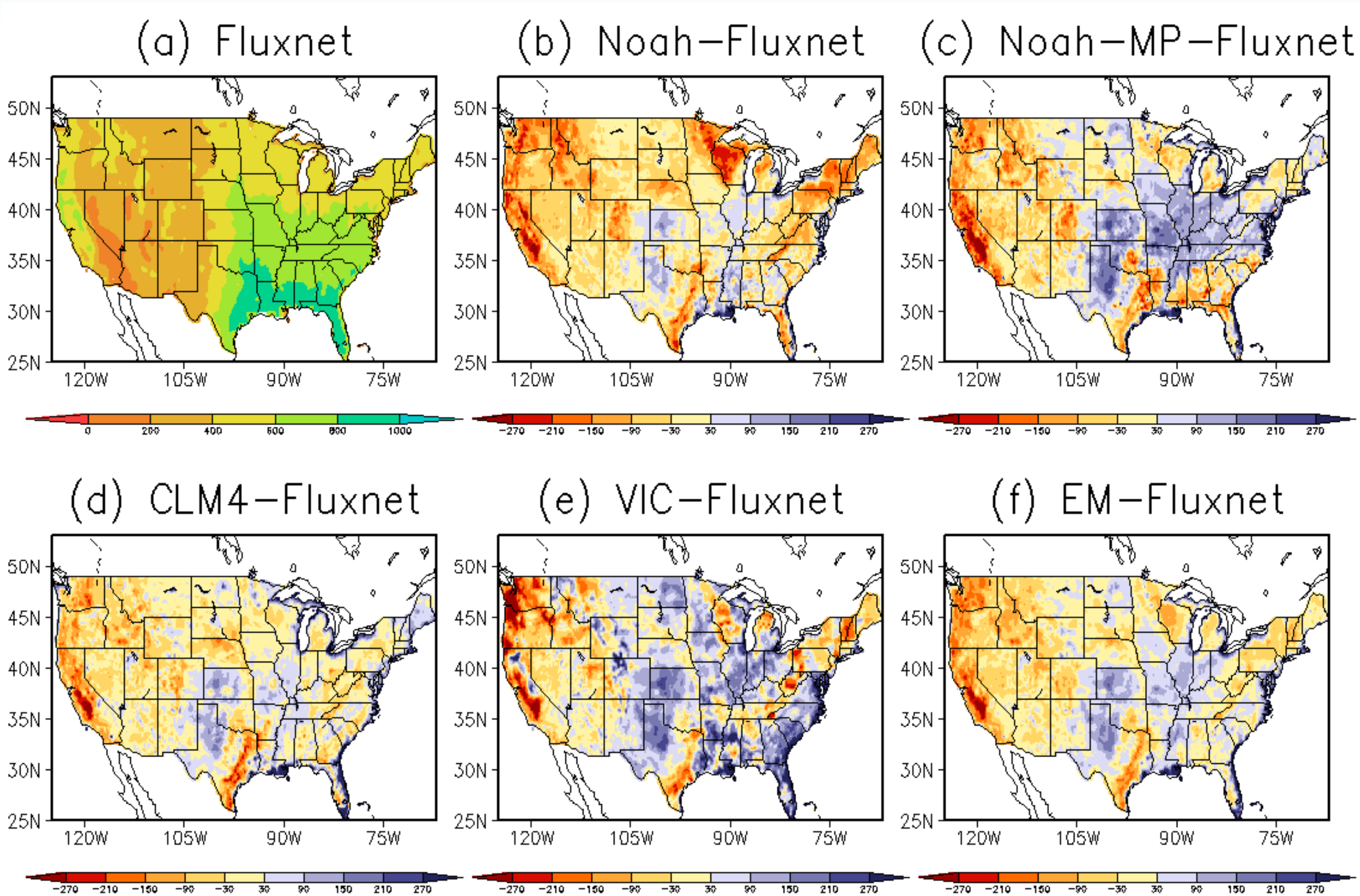
Comparison of ET, Fluxnet&MODIS vs. LSMs



Noah-MP and VIC simulated ET increases fast in growing season over eastern regions; while Noah too slow.

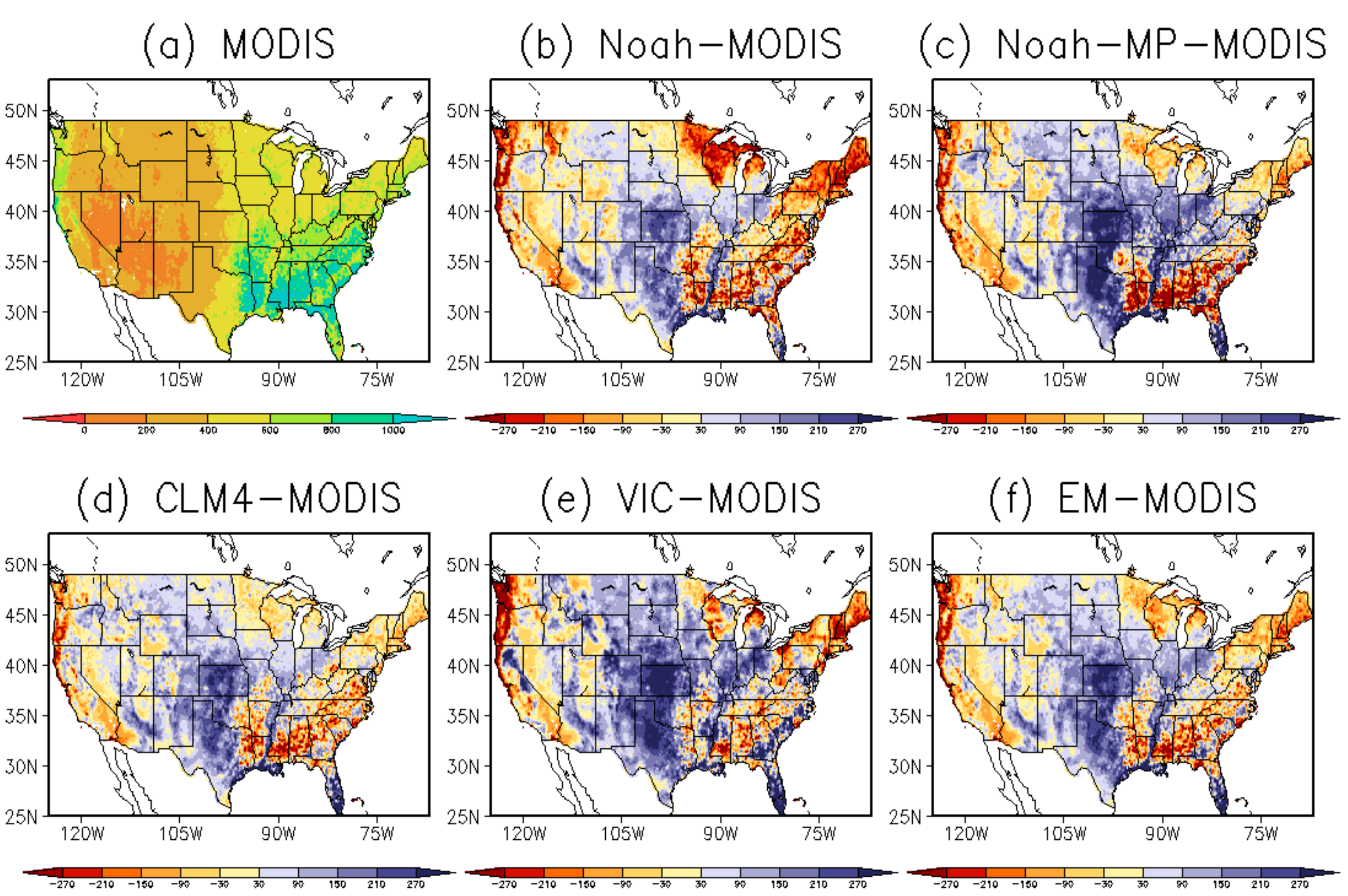
CLM4 shows the best agreement with observation.

Annual ET (LSMs – Fluxnet)



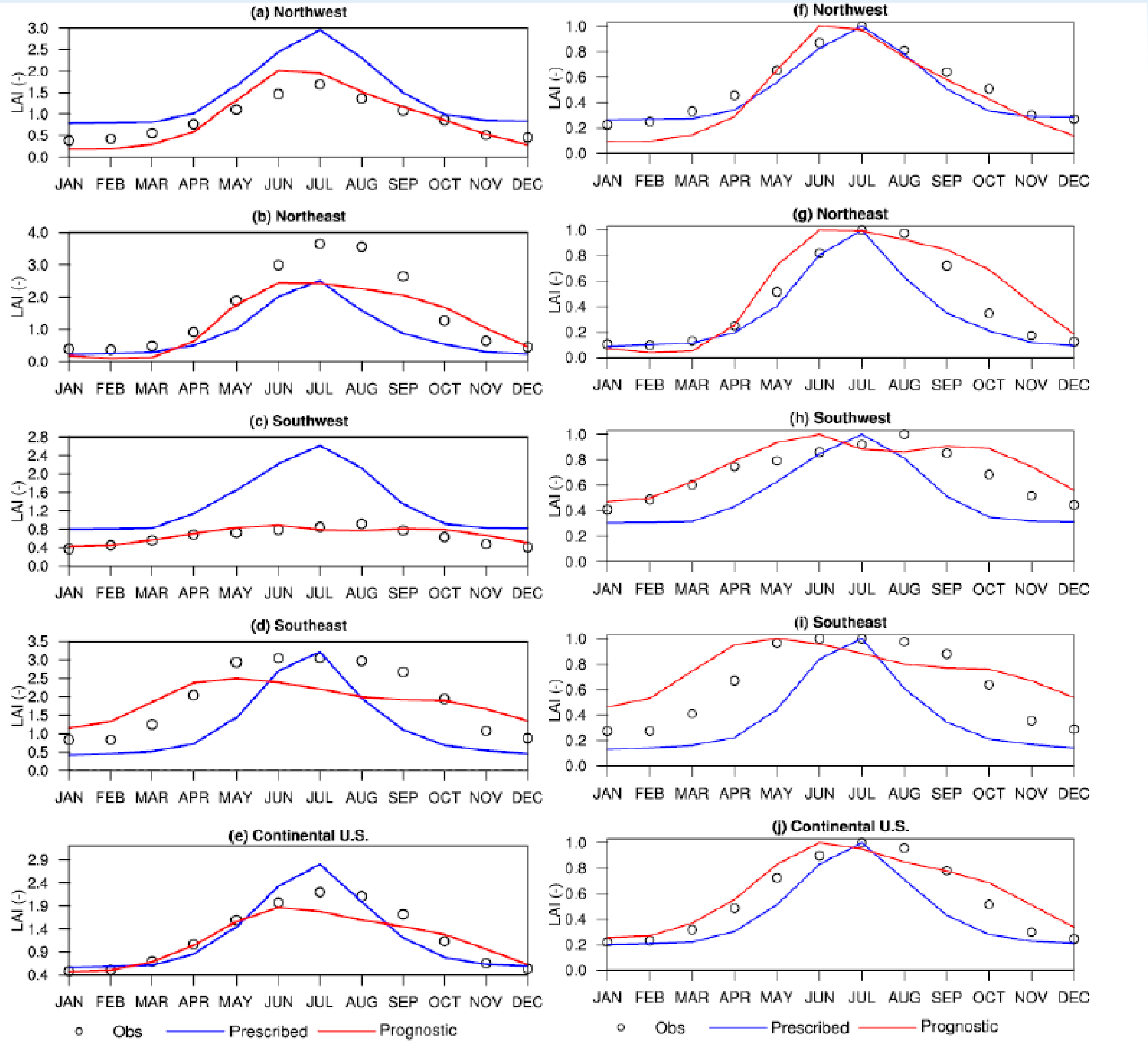
- All models underestimate ET over the west coast region.
- Noah underestimates ET; while Noah-MP and VIC overestimate.

Annual ET (LSMs – MODIS)



Negative bias over the southeast region, which may be due to bias in MODIS.

Comparison of Noah-MP and Satellite LAI



Cai et al. (2014), JGR

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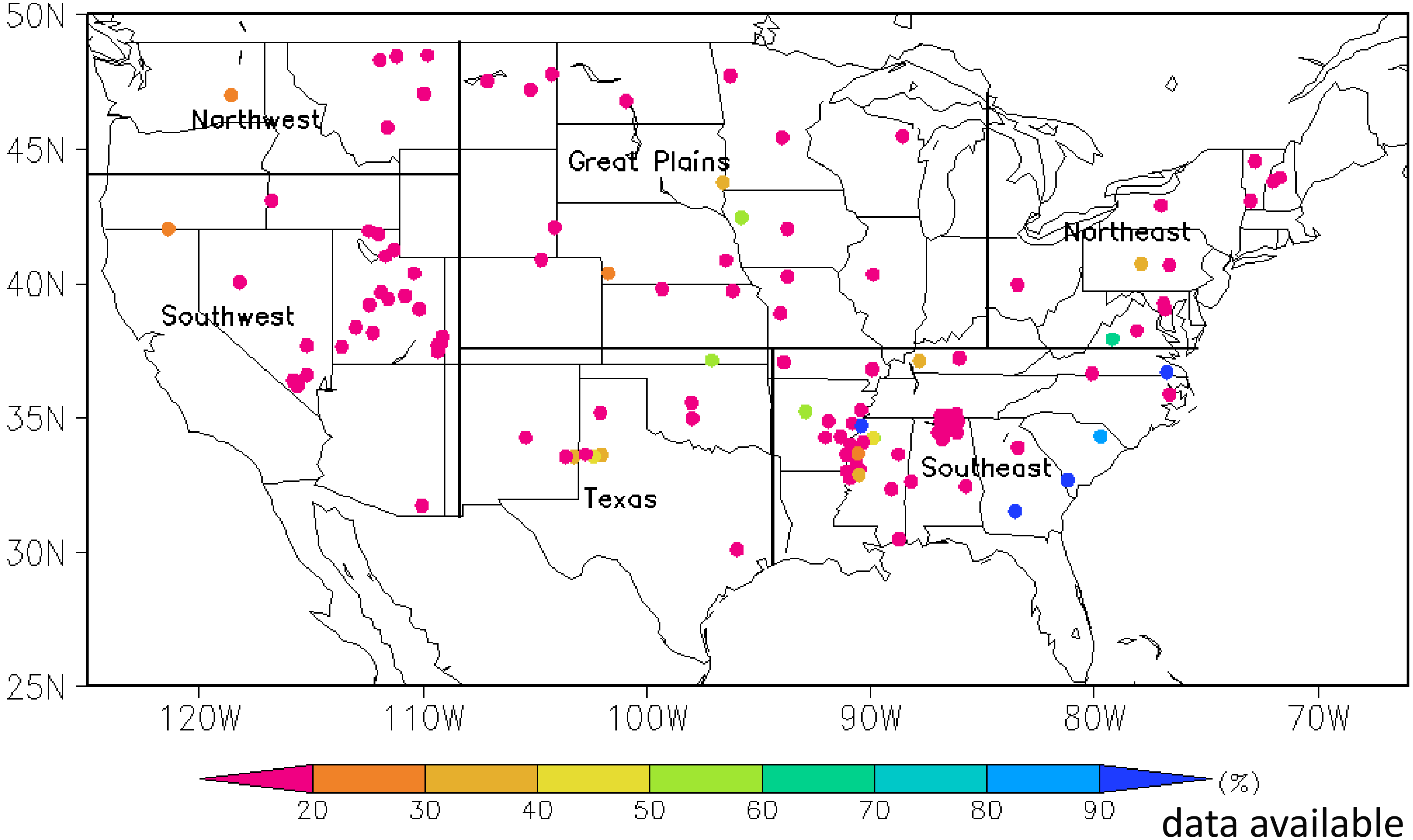
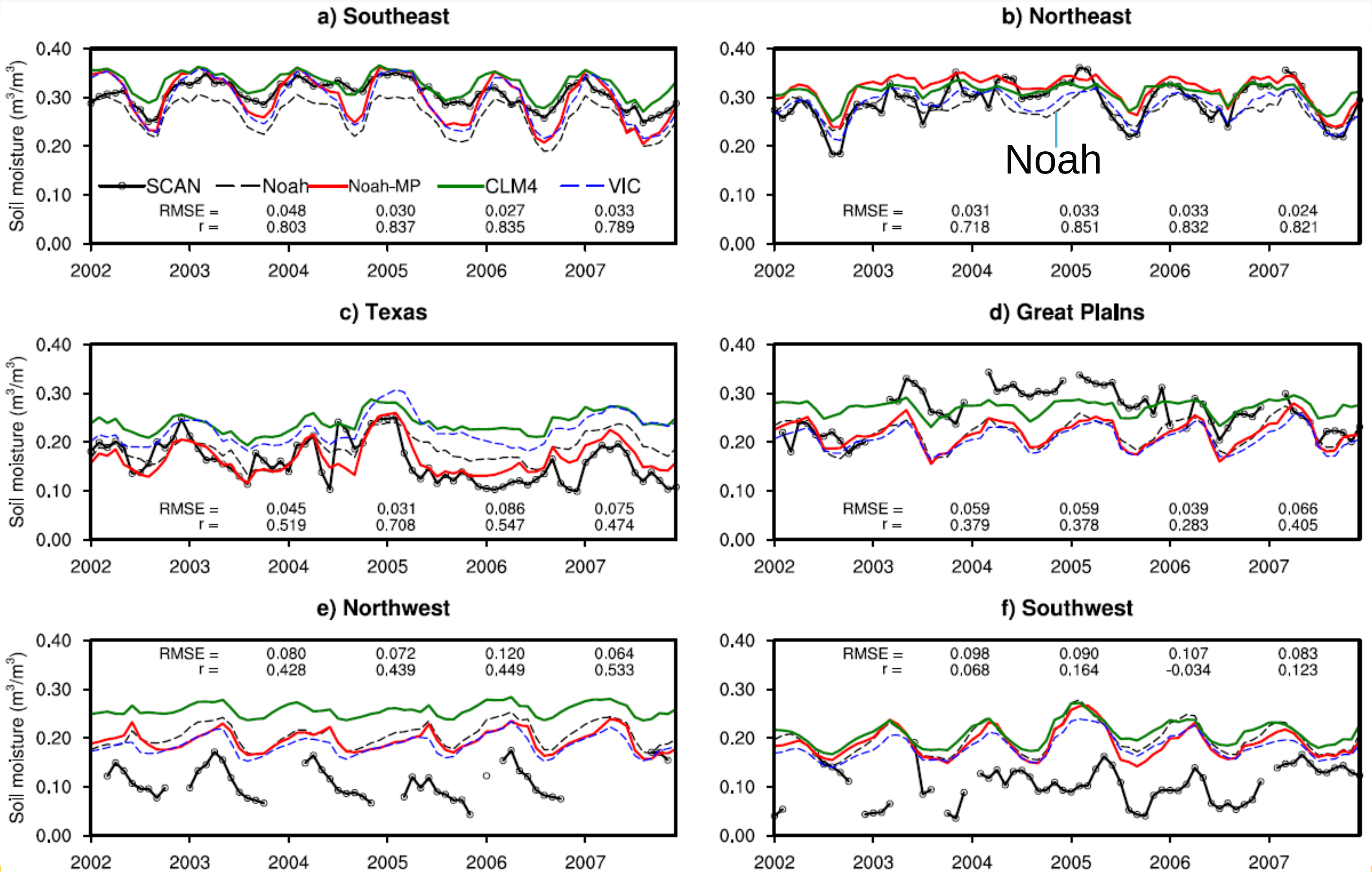
Soil Moisture

SCAN site locations and data availability



- SCAN: Soil Climate Analysis Network.

Comparison of Soil Moisture (Top 1 m)



- All LSMs perform well in the Eastern US, but not well in the Western US.
- Noah-MP is among the best in all the 6 regions.
- The amplitude of CLM4 simulated soil moisture is relatively small.

Conclusions

- Noah-MP, CLM4, and VIC capture the overall water cycle, based on their performance in the terrestrial water storage modeling.
- Noah-MP and CLM4 perform as well as VIC in runoff simulation.
- CLM4 shows the best agreement with ET observations.
- Noah-MP shows the best performance in soil moisture modeling.

Questions

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Thank you!